

FUTURE E/E-ARCHITECTURES IN THE SAFETY DOMAIN

Dr. Michael Bunse,
Dr. Matthias Wellhöfer,
Dr. Alfons Doerr

Robert Bosch GmbH, Chassis Systems Control, Business Unit Occupant Safety
Germany
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ABSTRACT

The number of functionalities, sensors and control units in modern vehicles is increasing permanently. In spite of this, the OEMs aim to minimize these numbers to reduce complexity, effort and cost. Thus it is very important to find the most suitable E/E-architecture jointly with the OEM in order to cope with these challenges. Furthermore, the repartitioning of content in the safety domain offers great opportunities for the OEM.

First of all, it can reduce the overall costs, since the trend towards increasing active and passive safety systems offers synergies of components and functions:

Driven by legislation, the installation rates of safety features like ESP® will rise significantly in some regions. Together with the fact that airbag systems in the triad markets have a take rate of almost 100% it is clear that there will be high potential in developing cost effective E/E-architectures.

Consequently two main steps are necessary to cope with these challenges: The first step is finding a suitable integration concept for inertial sensors on the vehicle architecture level. The second step is cost optimization by using maximum synergies or high-integration concepts.

Beyond cost reduction, the current functionality can be improved since the inertial sensors are directly connected on the same PCB-board with the airbag-algorithm controller in some integration concepts. This gives the possibility to feed the airbag-algorithm with inertial sensor data like for example the yaw rate. This yaw rate can be used in a yaw rate based airbag algorithm to further improve the performance.

This paper gives an overview about the architectures and functions, discusses the pros and cons of the different concepts and gives an outlook for future systems.

fatalities by 2010. By end of 2007 a significant reduction of 24.6% has been reached [2]. This is a clear progress, but without further increase of effort, the goal of 50% will not be achieved.

Important means to realize higher safety in public transport are the introduction of active and passive safety systems into the passenger cars. As passive safety systems we understand systems which reduce the consequences of an accident. Injuries will be reduced in severity and fatalities partly avoided, e.g., by use of safety belts and airbags. Active safety systems, however, mitigate the crash severity or even avoid the crash by stabilizing the vehicle in critical situations, shorten the braking distance, and avoid skidding, e.g., by electronic stability program (ESP®).

These safety functions are proven to be helpful to increase safety in the vehicle. However, they increase the number of electronic control units in the vehicle and therefore increase complexity and cost.

For more than ten years, new vehicles are equipped with passive safety as standard equipment in Germany. Together with the very high acceptance of the most important passive safety device - the safety belt - these systems have achieved a very high distribution in road traffic. As a consequence, the number of traffic fatalities has been significantly reduced, together with other factors by more than 32%, in spite of an increased mileage per person. The high market penetration of passive safety systems in Germany and Europe is due to legislation as well as to the work of consumer test organizations.

Active safety functions are far less abundant in the vehicles on the road. However, also these systems are beginning to gain effectiveness through higher take rates due to legislation (e.g., in the U.S. for newly released vehicles from 2012) and consumer test organizations (e.g., EURO-NCAP, safety rating)

INTRODUCTION

Approximately 40,000 people are still killed every year in the European Union [1]. Also in North America the number of traffic fatalities is too high. In 2001, the European Commission has stated the goal to achieve a 50% reduction of the traffic

Safety functions and E/E architecture of the vehicle

The introduction of additional safety systems into the vehicle increases the number of electronic control units and therefore also weight, energy

consumption, complexity, and costs. Safety functions will develop high effectiveness when they are introduced as standard equipment. In this case an optimized solution with respect to cost, weight, and energy is needed.

Analyzing the possibilities of architecture development reveals that the optimization of the E/E-architecture can mean that the current borders between active and passive safety have to be eliminated. Some improvements and cost reductions can only be realized if active and passive safety systems are merged to a safety domain in the passenger car.

In consequence, three different E/E-architectures are currently developed as optimized vehicle architectures in respect to integration of the inertial sensors for vehicle dynamics control. Today these sensors are ideally mounted close to the center of gravity. The three different integration approaches are:

- Integration into the brake control unit: *ESP®i*
- Integration into airbag control unit: *ABplus*
- Integration into a domain control unit with functional extensions: (DCU)

The three architecture variants offer characteristic advantages in respect to cost, weight, packaging and energy consumption, as well as possible sensor synergies, raising the question: Which of the solutions is the best one? As so often, the answer is not a simple and general one. Therefore an analysis of the systems with pros and cons is given below, providing a basis for making the correct decision in specific projects.

Architecture Variants

ESP®i

The *ESP®i* control unit is a standard *ESP®* control unit with integrated inertial sensors. This means that the sensors which are usually mounted separately in the central *ESP®*-Sensor cluster are now integrated in the *ESP®* control unit, located directly at the hydro aggregate. Therefore, the separate *ESP®* sensor cluster can be omitted. Since in the *ESP®i* architecture no connection to another system is necessary, it is an independent system. An *ESP®i* system usually covers the base functions like *ESP®*, hill hold control (HHC) and hill descend control (HDC).

ABplus

An *ABplus* control unit offers all functionalities with respect to state of the art crash sensing for passive safety: front, side, and rear crash detection. Furthermore, rollover detection, precrash functionality and pedestrian protection can be realized optionally. As described recently [3], the

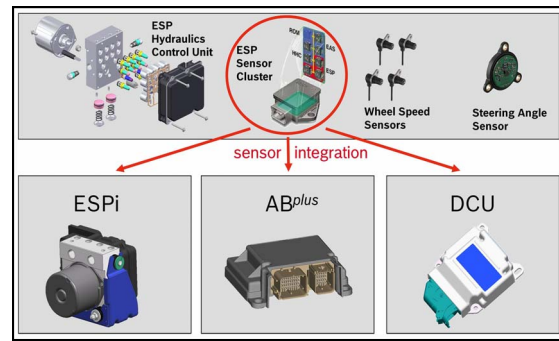


Figure 1: Overview of integration concepts for inertial sensor cluster function. *ESP®i* and *ABplus* mean integration into another existing Electronic Control Unit (ECU), DCU allows for high flexibility in functional extension.

inertial sensors for vehicle dynamics control of the *ESP®*-system are additionally integrated into this airbag control unit. Usually these sensors are located in a separate sensor cluster which is ideally mounted on the vehicle tunnel close to the center of gravity. With the *ABplus* approach this additional *ESP®* sensor cluster can be omitted. The integrated angular rate and acceleration sensor data are broadcasted via CAN interface to the brake ECU. The data are used in the brake system to prevent the vehicle from instable driving situations. Once the interface between the *ESP®* system and the airbag system is established, *ESP®*-based CAPS (combined active and passive safety) functions can be realized with a reduced networking effort. *ABplus* is available in a variety of configurations. In addition to the standard *ABplus* version with integrated *ESP®* sensors, *ABplus roll* offers additional sensors for rollover mitigation and protection. The configuration *ABplus 6D* contains a complete set of angular rate and acceleration sensors for all three dimensions. In addition to *ESP®* and rollover protection, it can also support chassis control functions like active damper control.

DCU

The Domain Control Unit (DCU) is a scalable central software and hardware integration platform in the vehicle. The functionality can be compared with a network server in the computer world. By analyzing all vehicle movements with the integrated inertial sensors, the DCU is the ideal home for all applications with high requirements like "Vehicle Motion and Safety" (VMS) and "Vehicle Dynamics Management" (VDM). A VDM function allowing for steering control on the basis of *ESP®* data can still be calculated by the *ESP®* ECU, but the networking of *ESP®* with damper, chassis and drive train requires more computing power which can be provided by the DCU.

Equipped with a powerful controller, the DCU is highly scalable and contains inertial sensors up to all three axes. That means low-g acceleration sensors as well as angular rate sensors. The system is also capable of integrating redundant sensors if required. Additionally, a DCU can also include the typical high-g acceleration sensors and angular rate sensors used for passive safety.

To measure the vehicle motion, the optimum position of the DCU is close to the center of gravity of the vehicle right on the vehicles transmission tunnel.

In the case of integrated passive safety sensors, the DCU is connected via PSI5 interfaces to the airbag control unit which does not contain sensors anymore. The relevant sensor values for the occupant safety function are sent by the DCU. Since the airbag control unit has no internal sensors left, the mounting requirements about fixation, orientation and geometry are reduced. Consequently there is no need for a special mechanical transfer function from the fixation points via housing and PCB to the sensor element. With this, the airbag control unit does not necessarily have to be located on the tunnel, but can be mounted at any position within the passenger compartment where the space is less limited.

Drivers for selection of optimum architecture

Market view

Three different solutions are available to be selected as E/E architecture of the vehicle. As the requirements and the decision of the architecture depend on the functional requirements it is important to analyze the market situation for active and passive safety systems.

Passive safety and its functionality are strongly driven by consumer tests and legislation. The status is that in Europe, North America and Japan, basically all newly released vehicles are equipped with standard airbag functionality. Increasing number of restraints and control loops is seen with increasing vehicle price and standard. The airbag system with front crash protection is basic functionality.

Side crash becomes more and more standard in B and C segment, whereas roll over protection is additionally offered in convertibles and Sport Utility Vehicles (SUVs), as well as vehicles of the D and E segment.

The active safety in form of ESP® on the other side is currently still not standard equipment even in Europe in many vehicles of the A and B segment. Starting with the C-segment the take rate of ESP® in newly bought vehicles is strongly increasing in Europe. In the E and F segment additional driver

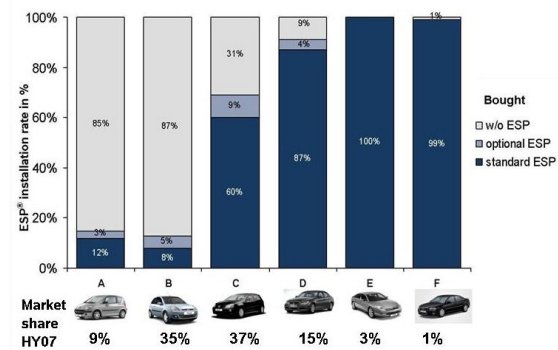


Figure 2: ESP® installation in major European markets (D, F, I, ES, UK) 2006 by car segment – optional and standard equipment. Source: Bosch figures in installation rates by new car registrations.

assistance functions extend the functionality of the active safety.

Looking at the vehicle segments, we find that the different classes are not equally equipped with the safety features of active and passive safety. Starting with basic passive safety without active safety we find a lot of vehicles in the A and B segment. Increasing equipment with active safety in form of ESP® and passive safety with side crash protection is found in C and D class. In the upper segments passive safety and active safety are standard, further functions of driver assistance and comfort are also extending the functionality of the active safety in these passenger cars.

These relations between active and passive safety are quite different in the other important markets of the world. Legislation activities and consumer test organizations also have influence on the distribution and development of the markets. Thus the analysis is necessary to be done for the specific target of the vehicle as a product.

Functional view

Because of the optimized functionality and the big advantage of being an independent system, the ESP®i architecture finds its main market volumes in the vehicle segments A-C, mainly addressing the span from the mini class up to the medium class. Especially small vehicles with limited functionality and ESP® installation rates below 100% are the ideal candidate for ESP®i, since this ESP® system is not interacting with other networking partners like the passive safety system.

The *ABplus* architecture typically has the main volumes in medium class vehicles from segment B to E, similar to the standard architecture with a separate ESP® sensor cluster. This is easy to understand since both cover the same technology

and the technical features are the same, the difference in many cases is only the housing. An additional main focus for *ABplus* is in the vehicle segment G and H which cover the pick-ups, SUVs and vans. Especially in the US these segments are often equipped with *ABplus* since ESP® will be mandatory in 2012 and a roll over legislation is expected as well. Therefore an *ABplus roll* with standard ESP® and rollover mitigation and protection is a smart solution to cover the requirement at lowest costs. Since *ABplus* uses the standard technology known from the separate sensor cluster the technical risk is also very low. Sensors synergies are possible in this architecture, where active and passive safety are connected and exchange data.

The DCU provides a fully AUTOSAR compatible software integration platform with an enormous controller power where a lot of functions can be integrated very easily. From damper control over active front steering up to a complete domain control the DCU offers a lot of opportunities to even integrate a lot of customer specific AUTOSAR software modules. Therefore it is clear that the DCU covers a broad band over the segments with main volumes in the D to F segment, which range from the upper medium class up to the luxury class.

Introduction of extended functions: Vehicle Motion Observer

Besides the trend towards new E/E architectures and different hardware/software integration concepts, there is a strong drive to integrate inertial sensors. Low-g acceleration and roll rate sensors around all three axes (so called 6D sensing systems) are the enabling technology for new powerful features: Based on the acceleration signals and roll, pitch and yaw rate the trajectory of the vehicle as a rigid body model can be described and measured very precisely in space. This gives the opportunity to create a so called "Vehicle Observer", an algorithm which calculates important parameters of motion. The Vehicle Motion Observer (VMO) therefore provides a platform for improving and developing innovative functions for the domains of safety, agility and comfort. Based on theory a motion of a vehicle, which in first order can be seen as a rigid body, can be described by kinematic and kinetic differential equations. With the input values from the 6D inertial sensors, the different wheel speeds and the steering wheel angle the VMO computes besides processed 6D signals a sideslip angle, roll and pitch angles as well as different vehicle velocities. Additionally other vehicle parameters like the mass and information about the driving environment

(road) and situation is available. Solving the rigid body differential equations in combination with Kalman-filtering is state-of-the-art for aviation. Nevertheless these algorithms are complex and need a lot of computational power. Therefore the VMO can be easily integrated in a powerful computer platform like the Domain Control Unit (DCU). Standard estimator algorithms are usually model based, this means the tire and vehicle model influences the results. The model uncertainties and the sensitivity with respect to parameter variation limit the accuracy of the estimation especially during high dynamic maneuvers the estimation is not accurate. The VMO based on the 6D computation has the big advantage that the rigid body differential equations give an exact kinematic relation, so the values can be computed exactly. This approach is independent from any vehicle or tire model and does not depend on other vehicle parameters. Since the VMO calculates instead of estimates output values the equation results are robust against parameter variation.

The determination of vehicle ego motion implies the computation of vehicle velocities v_x , v_y , v_z , sideslip, roll and pitch angle as well as inertial sensor signal processing like offset, orientation and gravity compensation, filtering and differentiation. The improved quality and reliability of the ego motion enables new functionality. On the other hand the quality of environment recognition (banked curves, slopes and friction coefficient) and of driving situation (over and under steering) are improved compared to conventional estimation techniques. Furthermore the vehicle mass and the center of gravity can be estimated precisely with the VMO. Therefore the VMO enables new and more precise functionalities.

Current crash sensing strategy and potential of yaw rate data to increase performance and functionality

In a vehicle crash, the activation of restraint devices is basically defined by crash type and crash severity. Both, the crash type and the crash severity to be expected are nowadays evaluated by the combined analysis of signals from acceleration, roll rate and pressure sensors. In high performance systems, surround sensing sensors (e.g. radar) can be integrated in the vehicle also providing data for the passive safety system.

The acceleration sensors serve to evaluate the acceleration signal waveform and the velocity change in the longitudinal and lateral directions. With the roll rate information, a prediction of a vehicle's rollover movement can be evaluated. By means of the pressure sensors, side crash events with deformation of the doors are rapidly

recognized and classified. The surround sensing system serves to detect relative velocities of approaching objects and estimate the time-to-impact (TTI) as well as the overlap. Current sensor configurations and evaluation algorithms are designed and applied on the basis of typical single crash scenarios. An integral part of the corresponding restraint system tests are separated into pure front, side and rollover scenarios. In general, the total kinetic energy of the vehicle and the crash opponent is converted to deformation energy due to the linear deceleration. The combined observation of linear acceleration and yaw rate has so far been of minor importance for crash classification. In a real world crash situation, however, the combination of the linear acceleration and yaw rate changes of the vehicle are expected to occur frequently during a crash. Typical scenarios with high yaw rate are low overlap crashes or non-centered crashes. For these crash scenarios, the longitudinal and lateral acceleration together with the yaw rate signal adequately describe the vehicle movement during the crash. Detailed analysis of the data reveals crash type and crash severity in real world crash situations in terms of impact point and impact direction with respect to the vehicle's center of gravity. While a full frontal crash may reveal high longitudinal deceleration and no yaw rate signal at the point of time where activation of restraint systems is required, offset crashes of similar severity may reveal much lower longitudinal deceleration but high alteration of yaw rate close to the optimum activation point. Today, the integration of a large number of restraints (with different levels of requirements for deployment decision) allows a better adaptation in real world crash scenarios. The application of force to the vehicle during the crash has a substantial influence on the movement of the vehicle, and therefore of the occupant. The activation of the various restraints is to be optimized for the relative movement of the occupant in a specific crash. This especially applies to the case of combined linear and alterations of yaw rate. While absolute value and duration of linear acceleration defines average crash severity, the yaw acceleration defines the variation of crash severity within the vehicle. A crash impact causing high rotational energy may lead to a moderate acceleration close to the vehicle's center of gravity, but a significantly higher acceleration value at places with larger distance to the vehicle's center of gravity. The yaw rate crash sensor is supposed to play an important role in the correct classification of real world crash scenarios, where crash adaptive use of various restraints may increase the effectiveness of the vehicle's safety system.

CONCLUSIONS

All three architecture variants *ABplus*, *ESP@i* and *DCU* are available to improve the E/E-architecture in the vehicle. Optimization for cost and weight, with optimized conditions for increased safety and environmental sustainability is possible. Since safety standards are different due to regionally determined legislation and market situation, as well as the distribution of functional requirements in the different vehicle types, a complex situation in respect to the requirements in current vehicle projects is the consequence. With respect to the question of optimum E/E-architecture it is clear that a general answer cannot be given. The optimum solution can be found, if these boundaries and conditions are taken into account. Together with the effects on vehicle level, project aspects, and organizational implications the E/E-architecture can be optimized for vehicle types and platforms.

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